The Role of Robotics in Human Mars Surface Exploration

Michael H. Sims

Synopsis

- The timing of Mars human exploration will largely determine what robots will be used
- In order to analyze the role of robotics in human surface operations I make the following assumptions: (These are outside the scope of current mission plans)
    - Mars settlement begins in 15 years
    - Mars permanent presence begins on 1st or 2nd landing
    - No sample return prior to humans
- Robotic menagerie for collaborative human-robotic exploration of Mars: Planetary Science rovers-Athena/MER class; Aircraft and lighter than air robotic vehicles; Assembly and maintenance robots; Robotic mules; Exploration buggies (think lunar buggies, ATVs); Winnebagos; Robotic assistant /graduate student; Robotic subsystems including immobile robots; Inspection robots; Indoor robotic assistant
- There is a need to do experimentation to understand:
    - how to use robots and humans synergistically in exploration
    - how to best use robots to support human planetary science activities
    - how to use robots to support ongoing survival functions (i.e., inspections)
    - how to build architectures of robots and intelligent systems to best support our goals
    - how to build software and hardware robustness sufficient to accomplish multi-year missions
    - how to organize and manage social environments to enable small crews in confined environments to remain productive and healthy
    - how to build sufficiently closed life support systems to enable missions
    - how to manage the information web needed both on Mars and on earth
    - how to reduce operations costs and burdens
- A dominate focus on revolutionary ideas is likely to lead to bad research and development. Progress is made by an ongoing, orderly process that builds on the strengths of the past and stays focused on clear goals while staying open to novel ideas which arise.

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A Classification of Needed Planetary Surface Robots

This paper should be interpreted as a thought exercise, and the point of view herein will sometimes be in direct contradiction to NASA' s current official positions.

Humans will eventually settle Mars. The real question is when. It will be in 1 decade or in 10 decades or sometime in between. In other words, humanity will have a second home soon in the grand scheme of things. It might take more than 10 decades, but that seems unworthy of us.

When we settle Mars is a societal choice. Given sufficient will by our society and governments the technologies and financing can work for any of these dates. It can be argued we are now closer to the knowledge and technologies needed to explore Mars than we were to the knowledge and technologies needed to explore the Moon when Kennedy announced that commitment. The cost of initial Mars settlement will be expensive but still on the order of major military programs.

The tools we use to explore Mars will depend crucially on when we choose to settle Mars. We will use very different robots for the initial settlement of Mars if settlement occurs one decade from now as opposed to occurring 10 decades from now.

So, in order to evaluate the robotic needs for human Mars missions we must make an assumption of when that settlement occurs. It is my observation that most strong disagreements about the human exploration of Mars occur as a consequence of differing, hidden assumptions about <u>when</u> settlement will occur.

Assumptions for this thought experiment

In order to proceed I will make a rather arbitrary assumptions for this thought exercise.

I. The permanent human settlement of Mars will begin in 15 years. Clearly this is a very ambitious goal. As Kennedy said "we choose these goals not because they're easy ... [because we are] unwilling to postpone". This assumption is consistent with five years to decide on this goal and 10 years to do the job. This assumption makes the analysis of robotics far easier because we have a reasonable chance of predicting the technologies. The planned robotic missions through 2007 are consistent with this assumption.

II. Permanent human presence will occur on the first or second human landing. Each Mars landing contributes to the building of an infrastructure. To continue to build that infrastructure at a given location is far more significant than the location itself. In part this is because of the advantage scientifically and practically of early human presence at that location. To survive on the Mars surface for many months requires a great robustness of the landed systems. Permanent survivability is arguably only marginally more difficult. Hence, the argument for immediate or early settling into a permanent presence.

III. I will assume no sample return prior to human Mars missions. A requirement of a sample return mission prior to human missions adds roughly a decade to the timeline for human arrival. This would be inconsistent with the 15 year assumption in I. above. In addition, if humans are going to arrive in 15 years then prior sample return will only lead to a marginal speed up in the scientific analysis of the environment. Some mission scenarios allow for a short stay and early return in case of extenuating circumstances, environmental or otherwise. A prior sample return for purely engineering reasons needs to be examined closely, especially for its financial and schedule implications. Crew contamination due to Mars indigenous biology is widely believed to be unlikely and even a robotic sample return will add little confidence to that belief due to the smallness of the returned sample relative to possible sites. Hence, this argues that a robotic sample return makes sense if human missions are several decades away, otherwise it may make sense to delay sample returns until after human arrival. This is analogous to the US doing no lunar sample return prior to the Apollo missions.

It would be valuable to consider alternative assumptions. We could repeat this exercise for longer periods (say 4 decades) until permanent presence on Mars. However the wild speculation quotient for the technology projections increases rapidly with time and we quickly reach a state where it is necessary to invoke “and then a miracle occurs” in our projections.

A classification of robot types for Mars exploration

Given the above assumptions, a classification of general types of robots that will be useful for Mars exploration follows. This classification is not exhaustive and is intended to clarify the distinct uses and types of robots. The names for these types of robots are intended to convey the intended use of these robots.

- Planetary Science rovers-Athena/MER class
- Aircraft and lighter than air robotic vehicles
- Assembly and maintenance robots
- Robotic mules
- Exploration buggies (think lunar buggies, ATVs)
- Winnebagos
- Robotic assistant /graduate student

- Robotic subsystems including immobile robots
- Inspection robots
- Indoor robotic assistant

Depending on the type of robot their will be different requirements. A planetary science rover may only need slow, safe navigation of the Mars terrain, an exploration buggy or Winnebagos may need fast, safe navigation in the Mars terrain and an immobile robot may require no navigation. An inspection robot might be largely teleoperated and an aircraft might be only seldom teleoperated. Classification of mineralogy based on spectral signatures may be important for planetary science rovers but may not be valuable for immobile robots. On the other hand, the immobile robot habitat will have a critical function of fault diagnosis. These represent different vectors in the space of possible autonomies and need different requirements specifications. The challenge for technology development is to understand the specific needs and then find solutions to these needs that are critical.

There are also technologies that cut across these types. For example, we would like any of these robots to be controllable from Earth, from Mars or from an astronaut. In addition, this control should be possible from the lowest level of teleoperation and actuator control to the highest levels of task control.

A few comments on a couple of the above robot classification follows:

Robotic assistant/graduate student

The idea of a virtual or robotic graduate student is great as a stimulant to research and the pushing of the envelope. As technologies improve these virtual graduate students' abilities will get more and more embedded in our robotics systems in a natural way. On the other hand many of the capabilities that are envisioned in a robotic graduate student are not essential for the exploration of Mars by humans within the next 15 years. These kinds of capabilities will probably be valuable for longer timelines.

Assembly and maintenance robots

Examples of assembly and maintenance robots would be construction cranes, bulldozers, cable laying devices, etc. Assembly and maintenance robots will be the most important robotic devices for enabling human settlement. For example, the deployment of habitat components prior to human arrival as specified in the Mars Reference Mission will:

- Enhances safety: verification of human habitable environments prior to crew arrival.
- Saves cost: can be done without sending human crews for these activities.
- Allows gradual component deployment without human survivability issues.

Specific uses of these devices will include deploying solar panels, deploying reactors, making electrical connections, deploying inflatables, and doing inspections. With proper design of components much of this is currently within the state of the art.

Steps on the road to permanent Mars settlement in 15 years

Given the above assumptions it is useful to lay out the following list of steps on the road to permanent human settlement.

- planetary rovers and orbiters explore Mars
- after fixed period of time a couple of sites are selected as possible human settlement sites
- exploration rovers are sent to those sites
- explicit site is chosen for the initial human settlement (satisficing criteria not optimization)
- human precursor equipment is landed and base site is established roboticly
- once setup is verified then humans launch
- humans land and establish settlement
- robots aid humans in scientific and other activities - full spectrum of vehicles.

In addition, such a human exploration program will require enhancing our understanding in many areas as well as refining our engineering prior to human launch. Such investigations will take place in a number of venues probably including laboratories, Mars analog setups and sites, LEO and on the Moon. For example, one investigation might be the missions of doing a robotic establishment of a Mars Reference Mission-like base on the Moon followed by astronaut occupancy.

A Program to Understand Needs

There is a pressing need to do experimentation to understand:

- how to use robots and humans synergistically in exploration
- how to best use robots to support human planetary science activities
- how to use robots to support ongoing survival functions (i.e., inspections)
- how to build architectures of robots and intelligent systems to best support our goals
- how to build software and hardware robustness sufficient to accomplish multi-year missions
- how to organize and manage social environments to enable small crews in confined environments to remain productive and healthy
- how to build sufficiently closed life support systems to enable missions
- how to manage the information web needed both on Mars and on earth
- how to reduce operations costs and burdens

It almost goes without saying that the state of our understanding and the state of simulations currently require that we do analog simulations of various elements and at various levels of fidelity. These investigations will require a spectrum of disciplines and their corresponding methodologies. Each methodology will have strengths and weaknesses. For example, the cognitive sciences will be primarily observational and hypothesis verification-based and the engineering sciences will be largely interventional and performance-based, etc. Intervening in an ongoing experiment to make it work may drastically speed the learning process but often destroys any hope of hypothesis verification. Ultimately, what we want is a framework which will have clear, strong implications about what robots can and cannot do well and what people can and cannot do well, in terms of perceptual-motor activities, cognition and collaboration.

Recommendations

There are two fundamental steps ahead of us at the moment:

a) Understand the needs (requirements) for human-robotic collaborative exploration systems
b) Extend technologies sufficiently to meet the above needs

Brainstorming in an office is of little value for the understanding of a). What are needed are experiments that probe the onion more and more deeply. Development of specific robotic testbeds are of some value here. Crucially coupled with that is the need for ongoing analog studies. Observational studies, interventional studies and software simulation studies of science and operations teams at work have been done and should continue to be done.

In general, the more specific the analogs and studies have been the more valuable they have been. For example, a robot experiment in an interesting geological environment is perhaps an order of magnitude more useful than a similar experiment in a sandbox designed to simulate a geology. The probable cause for this is that it is the interplay between an environment and a team that leads to the quality of the simulation and if that is largely one sided (without a real geology) and the simulation is less valuable.

I would recommend a sequences of tests for each of the following:

- Astronaut training by analog simulations
- Scientist training by analog simulations – fidelity of tasks is crucial
- Tool refinement by use in analog simulations
- Cognitive science investigations of roles and team effectiveness
- Task specific robotic architecture demonstrations (e.g., autonomous power management by rovers; mobility robustness by a variety of architectures)
- High fidelity simulation environments for mission and activity planning
- Environments for knowledge presentation to operators and scientists – both on earth and on Mars
- Software environments which are easily and robustly adaptive to changing circumstances
- Robust computer systems for operations
- Robust robotic systems – both SW and HW
- Higher fidelity simulations of the Mars Reference Mission setup
- Human-robot experiments to test various roles

A comment on revolutionary ideas

I would argue that what we need is an ongoing, orderly process that builds on the strengths of the past and stays focused on clear goals. While at the same time, great ideas should be incorporated whenever they occur and are appropriate. Revolutionary ideas are a rare occurrence in any domain. I would suggest that programmatically this program rely on the same strategy that gave us Apollo and most of the physics of the 20th Century and that is an ongoing and orderly process that builds on strengths.

This report has addressed the role of human mission timing in influencing robotic needs, one possible set of assumptions about human missions to Mars, a classification of robotic devices that those assumptions imply and finally a set important investigations to be pursued.